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Agricultural Memorandum No 685

Soil moisture and field drainage operations

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1. Introduction

The moisture held in a heavy soil layer is taken to be indicative of it's plasticity, and so of the rate and extent to which the soil will flow together again, into the channel drawn by a drainage tool.

A soil moisture balance may be struck between incoming rainfall and the losses due to evapotranspiration (and possibly through drainage and surface run-off). We may, in theory, follow both the build up of a soil moisture deficit in the growing season and the rewetting of the soil profile in the autumn and winter period, with the eventual restoration of field capacity.

The papers of Memorandum No 580, based on neutron probe measurements under various field crops, were primarily concerned with water availability as a function of soil type and with crop water extraction as a function of available soil moisture during the growing season (ie during the phase when total soil moisture deficits are in general increasing). In passing the papers offer information on the soil moisture deficits that may lead to a transpiration check and so to reduced crop growth, but more importantly, in the present context, offer information on the water available and removed from the various horizons of the soil profile at any point in time.

If such information is linked with the success or otherwise of field drainage operations (sub-soiling, moling, mini-moling) in specific situations, then the possibility exists of relating soil moisture in and about the depth of the operation to the degree of success. The way is then open to devise criteria and procedures that would enable some comment on the likelihood of success before operations are carried out, and on the "time window" likely to be available for such operations in general.

Although there have been earlier attempts to study some weather aspects of drainage operations (as in Ag. Memoranda 597, 598, 599), the present note begins from the premise that the field problems are not necessarily simple, or well understood, and that for further progress, and to explain failures, it becomes necessary to generate new information and ideas; as far as possible any assumptions made in order to move ahead, have to be justified.

2. Soil water availability and extraction rates

In looking at field drainage problems here, we automatically restrict attention to the heavier lands and ignore the problems that may arise from high water tables and local topography and geology.

The maximum depletion of soil moisture reserves on the heavy but free draining Rothamsted soil (Ag. Memorandum 580) is taken to represent the maximum that might

be removed by any annual arable or grassland crop. The figures are now reproduced for convenience

LAYER	MAXIMUM AVAILABLE WATER
0–30 cm	60 mm
30–60	35
60–90	35
90–120	20
120–150	10
Total	160 mm

The decreasing availability of water with depth is seen as a function of porosity (or conversely of the degree of soil compaction) and as a function of root density and distribution.

The point now raised is whether in looking at the success of actual field operations for drainage, it should be assumed that the amounts of water available to, and capable of being removed by, the over-lying crop should be those deduced from the Rothamsted site, or whether, since by definition the site of the operation is poorly drained, the amounts of water for crop extraction should be smaller; by the same token there should also presumably be a question mark over the rates of water extraction. The apparent paradox that less soil water should be available on a poorly drained site would be explained by increased compaction and restricted rooting, compared with the freer draining site.

Some clue to the line to adopt is obtained from data from the minimum cultivation plots at Drayton EHF. This is heavy land where soil working is kept to the surface layers, and where there is evidence of some marked contrast in soil temperature, soil water and root density between the worked and unworked layers eg, above and below 15–20 cm soil depth.

More specifically, from the Rothamsted data, a model of crop water extraction for spring sown field beans was deduced (Ag Mem 580) which took note of the observation that in 1971 at Rothamsted a transpiration check was apparent by the time a net extraction of some 50 mm water had taken place from the top 30 cm layer of soil.

MAFF Technical Bulletin 73/4 (A progress report on Field Drainage Experimental Sites for 1972) carries information on soil moisture deficit on variously drained plots at Drayton in the 1972 growing season, where the crop was winter sown field beans. Now whilst it is true that we have no further information, it is reasonable to expect that the model of water extraction for spring sown and winter sown field beans should be much the same, if some allowance is made for their different stage of growth on a given calendar date. In fact it only proved possible to obtain some reasonable fit to the 1972 data from Drayton, provided the assumption was made that only 20 mm of water was freely available in the top most soil layer, and that when this was depleted, there was a transpiration check and a reduced rate of water extraction from the lower soil horizons. Some decrease (below the Rothamsted figures) was also necessary in estimates of the total water available to the field bean crop in various soil layers.

It would seem prudent at this stage not to adopt a single model of water availability and rates of water extraction, but to consider a range of models which might permit a range of drainage characteristics to be examined.

3. The rewetting of heavy soils

This is seen as the key problem.
There is ample consistent evidence from neutron probe data, from lysimeters and from tensiometers of the behaviour of the soil/crop system under drying phase of the soil moisture hysteresis cycle. There is commonly a progressive drying with depth; once the top soil layer has given up it's available moisture, successive layers are exhausted in turn. On heavy (clay) soil, the two arms of the cycle are in the limit to be associated with significant changes in structure and volume, with shrinking and cracking on the one hand, and swelling, on imbibition, on the other.

For the lighter lands and for those which do not show such hysteresis effects to any degree, the conventional model, on rewetting is of a progressive movement downwards of the wetting front, as water (rainfall) applied at the surface brings successive horizons back to field capacity.

It would seem that such a simple model may not always be valid for heavy land under a substantial deficit. There is evidence to suggest that in some situations, under heavy rainfall, there may be wetting down the complete soil profile on heavy land before the topmost soil layers are brought back to field capacity. Such an example is shown (Figure 1) by the Brooksby site of the Field Drainage Experimental Unit in 1974, and other, similar evidence can be produced from other sites.

The implications of this information are far-reaching. It suggests that whilst we may be able to indicate a time to the start of successful field drainage operations (as soil moisture deficits open up gradually under the influence of transpiration) that in distinct contrast, the closing of "time window" for successful operations may be sudden, rather than gradual, and to that extent capricious and unpredictable, depending on the arrival, forecast or probability of rainfall above a certain amount and rate of fall.

Before accepting that such is the situation, it is perhaps worthwhile to examine the evidence a little more closely.

There is the distinct possibility to be considered that the apparent re-wetting down the complete soil profile may not be real, but an artefact of the method of soil moisture measurement. The neutron probe measurements of soil moisture change are known to be susceptible to the movement of surface water down the outside of the access tube, where close contact with the soil is not always maintained. Such a process is known to lead to over-estimates of soil moisture content. But equally, if observations are continued in such a situation, into a subsequent drying period, there is not infrequently an apparent rapid drying of the soil over and above that due to transpiration (cf. Ag Mem 580) as the free water around the access tube is dispersed. Figure 1 in fact shows much the same rate of drying at all levels over the period from June 18 onwards as was observed over late May. More detailed calculations from June 12th to June 26th, taking into account observed rainfall amounts, suggests that the average daily transpiration loss was some 2.4 mm/day over the period 12-26th June, and some 3.0 mm/day over the period 16-26th June. Such transpiration rates accord with those to be expected in June and do not call for any special comment or pleading.

It would also seem prudent at this stage to consider some alternative models of rewetting and distributing substantial rainfall among the various soil horizons.

4. Estimates of soil moisture profile and their association with the success of field drainage operations

4.1 Using the possibly optimistic models of crop water extraction set down in Ag. Mem. 580, where the models assume progressive rewetting from the top layer down on all occasions (as distinct from rewetting down the whole profile under conditions of heavy rain), we obtain the sets of information indicated below. The data were worked up on a weekly basis throughout the season (using weekly totals of rainfall and transpiration), but only selected weeks are reported at this time.

Commonly, sub-soiling might imply operations at 60–70 cm depth, moling at 50–60 cm depth and mini moling at around 40 cm depth.

Site Drayton Year 1971

Crop Winter Wheat

Date (Week Ending)	Depth of soil layer								Total SMD in Profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 150 cm	
			30/40	40/50	50/60	60/70	70/90		
6/3/71	25 mm	35	12	12	12	1.2	.22	30	0 mm
28/8/71	25	35	1.1	0	0	10.1	22	30	36.8
4/9/71	15.5	35	1.1	0	0	10.1	22	30	46.3
11/9/71	0	35	1.1	0	0	10.1	22	30	61.8
18/9/71	0	35	1.1	0	0	10.1	22	30	61.8

The site was moled successfully (50 - 60 cm layer) on 14/9/71.

Site Drayton Year 1970

Crop Winter Wheat

Soil moisture available in various layers

Date (Week Ending)	Depth of soil layer								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		80 - 150 cm	
			30-40	40-50	50-60	60-70	70-90a		
7/3/1970	25 mm	35	12	12	12	12	2	30 mm	0 mm
22/9/1970	3.6	0	0	0	0	0	0	3.9	152.5
29/8/1970	25	31.0	0	0	0	0	0	3.9	100.1
5/9/1970	5.1	31.0	0	0	0	0	0	3.9	120.0
12/9/1970	0.1	31.0	0	0	0	0	0	3.9	125.0
19/9/1970	0	31.0	0	0	0	0	0	3.9	125.1

The site was sub-soiled successfully (60-70 cm layer) on 10/9/1971

Site Drayton Year 1969

Crop Winter Wheat

Soil moisture available in various layers

Date (Week Ending)	Depth of soil layer								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 150 cm	
			30 - 40	40 - 50	50 - 60	60 - 70	70 - 90		
4/3/1969	25 mm	35	12	12	12	12	22	30 mm	0 mm
19/8/69	18.2	35	12	12	8.6	0	0	28.2	46.0
26/8/69	8.5	35	12	12	8.6	0	0	28.2	55.7
2/12/69	25	35	12	12	12	12	22	30	0
8/12/69	25	35	12	12	12	12	22	30	0
16/12/69	25	35	12	12	12	12	22	30	0

The site was moled (50 - 60 cm layer) in December and the operation was a failure.

Site Layer Breton near Colchester Year 1970

Crop Winter Oats

Soil moisture available in various layers

Date (Week Ending)	Depth of Soil								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 150 cm	
			30 - 40	40 - 50	50 - 60	60 - 70	70 - 90		
1/1/1970	25 mm	35 mm	12	12	12	12	22	30	0 mm
31/1/1970	25	35	12	12	12	12	22	30	0

The site was moled (50 - 60 cm layer) in January 1970. The operation was a failure.

Site Layer Breton near Colchester Year 1971

Crop Winter Oats

Soil Moisture available in various layers

Date (Week Ending)	Depth of soil								Total SMD in Profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 150 cm	
			30 - 40	40 - 50	50 - 60	60 - 70	70 - 90		
10/4/1971	25 mm	35	12	12	12	12	22	30	0 mm
21/8/1971	0.1	0	0	0	0	0	0	29.7	130.2
28/8/1971	0	0	0	0	0	0	0	29.7	130.3
2/10/1971	0	0	0	0	0	0	0	29.7	130.3
9/10/1971	0	0	0	0	0	0	0	29.7	130.3

The site was moled (50 - 60 cm layer) on 5/10/71. The operation was a success.

Site Scredington near Sleaford Year 1966

Crop Spring barley

Soil moisture available in various layers

Date (Week Ending)	Depth of soil								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 150 cm	
			30 - 40	40 - 50	50 - 60	60 - 70	70 - 90		
7/3/1966	25 mm	35	12	12	12	12	22	30	0 mm
22/8/1966	4.5	4.2	0	0	0	0	21.8	30	99.5
29/8/1966	0	4.2	0	0	0	0	21.8	30	104.0
5/9/1966	2.7	4.2	0	0	0	0	21.8	30	101.3
12/9/1966	0	4.2	0	0	0	0	21.8	30	104.0

The site was moled on 12/4/1966. The operation was a failure.

Site Kettering Year 1969

Crop Spring barley

Soil moisture available in various layers

Date (Week Ending)	Depth of soil								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 150	
			30 - 40	40 - 50	50 - 60	60 - 70	70 - 90		
8/3/1969	25 mm	35	12	12	12	12	22	30	0
23/8/1969	2.6	6.8	0	0	0	0	0	0	150.6
30/8/1969	0	6.8	0	0	0	0	0	0	153.2
1/11/1969	0	6.8	0	0	0	0	0	0	153.2
8/11/1969	9.4	6.8	0	0	0	0	0	0	143.6
15/11/1969	25.0	11.5	0	0	0	0	0	0	123.5
22/11/1969	25.0	26.2	0	0	0	0	0	0	108.8

The site was being subsoiled successfully at a depth of 55 cm prior to the first week of November. After the heavy rainfall (around 22 mm in 3 days) late in the following week, work became completely ineffective.

Site Wilburton near Ely Year 1970

Crop Grass

Soil moisture available in various layers

Date (Week Ending)	Depth of soil								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 150 cm	
			30 -	40 - 50	50 - 60	60 - 70	70 - 90		
4/3/1970	25 mm	35	12	12	12	12	22	10	0 mm
19/8/1970	0	0	0	0	0	0	0	4.2	135.8
26/8/1970	8.7	0	0	0	0	0	0	4.2	127.1
16/9/1970	13.5	0	0	0	0	0	0	1.6	124.9
23/9/1970	5.4	0	0	0	0	0	0	1.6	133.0

The site was moled successfully (50 - 60 cm layer) on 22/9/1970

Site Brooksby Hall near Melton Mowbray Year 1969

Crop

Soil moisture available in various layers

Date (Week Ending)	Depth of soil								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 120 cm	
			30 - 40	40 - 50	50 - 60	60 - 70	70 - 90		
4/3/1969	25 mm	35	12	12	12	12	22	10	0 mm
22/7/1969	0	0	0	0	0	0	8.8	10	12.2
24/7/1969	25	7.4	0	0	0	0	8.8	10	88.8

The site was moled successfully (50 - 60 cm layer) on 30/7/1969

Site Cefn Coch near Welshpool Year 1971

Crop Grass

Soil moisture available in various layers

Date (Week Ending)	Depth of soil								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 120 cm	
			30-40	40-50	50-60	60-70	70 - 90		
2/3/1971	25 mm	35	12	12	12	12	22	10	0 mm
13/7/1971	0	5.1	0	11.1	12	12	22	10	67.8
20/7/71	0	0	0	0	5.0	12	22	10	91.0

The site was subsoiled successfully (35 cm layer) on 22/7/71 by the farmers own equipment. At lower depths the implement struck too many stones.

Site Langabeare near Okehampton Year 1964

Crop Grass

Soil moisture available in various layers

Date (Week En'ing)	Depth of soil								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 120 cm	
			30-40	40-50	50-60	60-70	70-90		
10/4/1964	25 mm	35	12	12	12	12	22	10	0 mm
24/7/1964	0	0	0	0	9.4	12	22	10	86.6
31/7/1964	2.2	0	0	0	9.4	12	22	10	84.4

The site was moled successfully (50 - 60 cm layer) on 29/7/1964.

Site East Worlington near Riverton Year 1965

Crop Grass

Soil moisture available in various layers

Date (Week Ending)	Depth of soil								Total SMD in profile
	0 - 30 cm		30 - 60 cm			60 - 90 cm		90 - 120 cm	
			30-40	40-50	50-60	60-70	70-90		
5/3/1966	25 mm	35	12	12	12	12	22	10	0 mm
20/8/1966	0	28.2	12	12	12	12	22	10	31.8
27/8/1966	25	35	12	12	12	12	22	10	0
3/9/1966	22.5	35	12	12	12	12	22	10	2.5
10/9/1966	25	35	12	12	12	12	22	10	0

The site was moled (50 - 60 cm layer) on 19/9/1966. The operation was a failure.

The weight of evidence coming from this study is that when the soil layer being operated on has been completely (or even partially) dried by the over-lying crop, then the sub-surface drainage operation is likely to succeed (7 cases out of 9); conversely, when the calculations suggest that the layer is wet (soil moisture in the layer that at field capacity), then the operation is likely to fail (3 cases out of 3). In both the cases where the layer of operation was calculated to be dry, but where the operation failed, there were periods of a week, or less in which the rainfall total exceeded 50 mm. The apportionment of such heavy rainfall down the profile obviously leads to a significantly different pattern of soil moisture in the profile for some time afterwards.

5. Alternative models of crop water extraction and rewetting

5.1 To take up the point of less water being available to crops on poorly drained sites, a progressive reduction of the maximum water available in the profile is proposed.

This is simply achieved by reducing the total available water in the Rothamsted profile by approximately 20% and 40%.

The distribution of the available water in the profiles should now presumably be biased in favour of the higher soil layers where most rooting takes place; the initial distributions proposed as being potentially available to cereals and grasses on 3 sites on heavy land showing a gradation in drainage characteristics are shown in the following Table 1.

Table 1

Available soil moisture in various layers under differing soil drainage characteristics

Soil Layer	Cereals			Grasses		
	Soil Characteristics			Soil Characteristics		
	A	B	C	A	B	C
0 - 10 cm	25)	20)	20)	25)	25)	20)
10 - 20	20) 60 mm	18) 50 mm	18) 50 mm	20) 60 mm	18) 50 mm	18) 50 mm
20 - 30	15)	12)	12)	15)	12)	12)
30 - 40	12)	10)	10)	12)	10)	10)
40 - 50	12) 36 mm	10) 30 mm	10) 27 mm	12) 36 mm	10) 30mm	10) 27 mm
50 -,60	12)	10)	7)	12)	10)	7)
60 - 70	12)	10)	7)	12)	10)	7)
70 - 80	12) 34 mm	10) 30 mm	7) 18 mm	12) 34 mm	10) 25 mm	1) 8 mm
80 - 90	10)	10)	4)	10)	5)	-)
90 - 100	7)	5)	2)	4)	2)	
100 - 110	7) 21 mm	5) 15 mm	2) 5 mm	4) 10 mm	2) 5 mm	
110 - 120	7)	5)	1)	2)	1)	
120 - 130	3)	2)	-)			
130 - 140	3) 9 mm	2) 5 mm	-) 0 mm			
140 - 150	3)	1)	-)			
Total	160 mm	130 mm	100 mm	140 mm	110 mm	95 mm

5.2 To take up the further point of water being less freely available on the poorer drained sites, a progressive decrease in the depth of the soil layer from which water may be extracted without a transpiration check is proposed.

This is simply achieved by reducing the depth of the layer between the situations A and B, and between B and C. For grasses, the depth of these layers are then 60 cm, 50 cm, 40 cm respectively.

5.3 To take up the question of distributing heavy rainfall down the whole profile depth, several alternative options would fit the limited observations available.

It is proposed that such a distribution of rainfall would first need an antecedent extraction of soil moisture sufficient to induce positive changes in soil volume and porosity. Such a state of affairs is assumed to exist after a total deficit in the profile has been achieved, equal to the freely available water in the top 30 cm of soil, ie, after a total soil moisture deficit of 60 mm or 50 mm is first reached, depending on assigned soil characteristics. The method of calculating the deficit implies that it is the topmost layers that dry first.

When this situation obtains and when rainfall > 8 mm now falls in a day, it is proposed that the rainfall should be distributed equally among all the soil layers above that which holds 50% or more of the available water at field capacity. Whilst rainfall is allocated on a daily basis, estimates of transpiration on a weekly basis are still seen as adequate.

The taking up of moisture in the soil rewetting phase in turn leads to changes in soil volume and porosity. In view of known hysteresis effects, it is not necessarily to be expected that the allocation of rainfall would revert to the more usual process (in which it is added to the topmost soil layer showing some deficit until that layer reaches field capacity) at the same soil moisture conditions at which a rainfall distribution down the full profile is begun.

It is proposed that the more usual rainfall allocation should be resumed when the soil layer immediately below the top surface layer (ie at 10–20 cm) holds 50% or more of the water freely available of field capacity. Equal allocation of rainfall down the profile leads quite naturally into this situation, as successive bursts of heavy rain ensure that lower, smaller capacity horizons reach 50% of the water available at field capacity before those above. Incoming rain is shared between progressively fewer soil layers and eventually, is allocated only to the topmost 0–10 cm layer.

6. Results

The results of applying the considerations outlined in section 5 to the data of section 4 are as follows.

Soil characteristic A plus rewetting down the profile

Crop Cereals

Site	Year	Maximum water available in layer														Success
		0/ 10 cm	10/ 20	20/ 30	30/ 40	40/ 50	50/ 60	60/ 70	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	120/ 130	130/ 140	140/ 150	
		25 mm	20	15	12	12	12	12	12	10	7	7	7	3	3	3	
		Water in profile at time of operation															
Drayton	1971	0 mm	9.1	9.1	9.1	9.1	[9.1]	12	12	10	7	7	7	3	3	3	Yes
Drayton	1970	10.7	10.2	10.2	7.2	7.2	[7.2]	7.2	7.2	7.2	7	7	7	3	3	3	Yes
Drayton	1969	25	20	15	12	12	[12]	12	12	10	7	7	7	3	3	3	No
Layer Breton	1971	0	5.6	5.6	5.6	5.6	[5.6]	6	12	10	7	7	7	3	3	3	Yes
Layer Breton	1970	25	20	15	12	12	[12]	12	12	10	7	7	7	3	3	3	No
Scredington	1966	0	17	8	8	8	[8]	6	12	10	7	7	7	3	3	3	No
Kettering	1969	25	18.2	9.3	6.3	6.3	[6.3]	6.3	6.3	6.3	4.7	4.7	4.7	3	3	3	Yes
Kettering	1969	25	20	15	12	12	[8.6]	6.3	6.3	6.3	4.7	4.7	4.7	3	3	3	No

[ ] denotes level of operation

Soil Characteristics A plus rewetting down the profile

Crop Grass

Site	Year	Maximum water available in layer												Success
		0/ 10 cm	10/ 20	20/ 30	30/ 40	40/ 50	50/ 60	60/ 70	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	
		25 mm	20	15	12	12	12	12	12	10	4	4	2	
		Water in profile at time of operation												
Wilburton	1970	0	0	0	0	0	[0]	0	1.5	2.5	0	1.6	2	Yes
Melton Mowbray	1969	0	0	0	0	2.7	[4.3]	4.3	4.3	7	4	4	2	Yes
Cefn Coch	1971	0	0	0	[0]	0	0	0	7.8	10	4	4	2	Yes
Langabeare	1964	0	0	0	0	0	[6.2]	12	12	10	4	4	2	Yes
East Worlington	1965	25	20	15	12	12	[12]	12	12	10	4	4	2	No

[ ] denotes level of operation

Soil Characteristic B plus rewetting down the profile

Crop Cereals

Site	Year	Maximum water available in layer														Success
		0/ 10 cm	10/ 20	20/ 30	30/ 40	40/ 50	50/ 60	60/ 70	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	120/ 130	130/ 140	140/ 150	
		20 mm	18	12	10	10	10	10	10	10	5	5	5	2	2	1	
		Water in profile at time of operation															
Drayton	1971	0	17	12	10	5.8	[5.4]	5.4	5.4	7.3	5	5	5	2	2	1	Yes
Drayton	1970	10.7	11.4	6.9	6.9	6.9	[6.9]	6.9	6.9	6.9	5	5	5	2	2	1	Yes
Drayton	1969	20	18	12	10	10	[10]	10	10	10	5	5	5	2	2	1	No
Layer Breton	1971	0	2.6	2.6	2.6	2.6	[2.6]	2.6	2.6	2.6	2.6	2.6	2.6	1.4	1.4	.7	Yes
Layer Breton	1970	20	18	12	10	10	[10]	10	10	10	5	5	5	2	2	1	No
Scredington	1966	0	15	6	6	6	[6]	3	3	7.7	5	5	5	2	2	1	No
Kettering	1969	20	18	7.8	6.3	6.3	[6.3]	6.3	6.3	6.3	5	5	5	2	2	1	Yes
Kettering	1969	20	18	12	10	10	[10]	6.6	6.6	6.6	5	5	5	2	2	1	No

[ ] denotes level of operation

Soil Characteristics B plus rewetting down profile

Crop Grass

Site	Year	Maximum water available in layer												Success
		0/ 10cm	10/ 20	20/ 30	30/ 40	40/ 50	50/ 60	60/ 70	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	
		20 mm	18	12	10	10	10	10	10	5	2	2	1	
		Water in profile at time of operation												
Wilburton	1970	0	0	0	0	0	[0]	1.6	2.8	2.8	2	2	1	Yes
Melton Mowbray	1964	0	0	0	1.6	5.1	[5.1]	5.1	5	5	2	2	1	Yes
Cefn Coch	1971	0	0	0	[0]	0	0	0	.7	5	2	2	1	Yes
Langabeare	1964	0	0	0	0	2.4	[5.5]	10	10	5	2	2	1	Yes
East Worlington	1965	20	18	12	10	10	[10]	10	10	5	2	2	1	No

[ ] denotes level of operation

Soil Characteristics C plus rewetting down profile

Crop Cereals

Site	Year	Maximum water available in layer											Success
		0/ 10 cm	10/ 20	20/ 30	30/ 40	40/ 50	50/ 60	60/ 70	70/ 80	80/ 90	90/ 100	100/ 110	110/ 120	
		20 mm	18	12	10	10	7	7	7	4	2	2	1	
		Water in profile at time of operation												
Drayton	1971	0	14.9	8.4	8.4	8.4	[4.8]	4.8	4.8	2	2		1	Yes
Drayton	1970	18	12.7	12	10	10	[7]	7	7	4	2	2	1	Yes
Drayton	1969	20	18	12	10	10	[7]	7	7	4	2	2	1	No
Layer Breton	1971	0	2.7	2.7	2.7	2.7	[2.7]	2.7	2.7	2.7	2	2	1	Yes
Layer Breton	1970	20	18	12	10	10	[7]	7	7	4	2	2	1	No
Scredington	1966	2.7	11	11	5	5	[5]	5	5	2	2	2	1	No
Kettering	1969	20	18	10.1	6.6	6.6	[4.6]	4.6	4.6	4	2	2	1	Yes
Kettering	1969	20	18	12	10	10	[7]	7	4.6	4	2	2	1	No

[ ] denotes level of operation

Soil Characteristics C plus rewetting down profile

Crop Grass

Site	Year	Maximum water available in layer								Success
		0/ 10 cm	10/ 20	20/ 30	30/ 40	40/ 50	50/ 60	60/ 70	70/ 80	
		20 mm	18	12	10	10	7	7	1	
		Water in profile at time of operation								
Wilburton	1970	0	0	0	0	0	[2.0]	2.2	1	Yes
Melton Mowbray	1969	0	7.2	5	5	5	[5]	2	1	Yes
Coch	1971	0	0	0	[0]	0	0	4.1	1	Yes
Langabeare	1964	0	0	0	0	0	[2.4]	7	1	Yes
East Worlington	1965	20	18	12	10	10	[7]	7	1	No

[ ] denotes level of operation

If the criterion for failure is that the available water in the layer in which the drainage channel is being drawn should be at, or close to, the water held in that layer at field capacity, then it is seen that the model employing soil characteristics B offers the best over-all interpretation of events.

The data from Scredington remain intractable on all the analyses and hypotheses employed.

The move from model A to model B picks up the transition from satisfactory to unsatisfactory working at Kettering; the further move from model B to model C introduces changes in the expected results at Drayton and Melton Mowbray which were "explained" satisfactorily on the model A and B hypotheses.

7. Conclusions

7.1 The best advice that can be offered at the present time on the likelihood of success or failure of drainage operations comes from the criterion above; a soil moisture balance is required to be struck, using the soil moisture characteristics assigned under B in Section 5.1, 5.2; the procedures for estimating crop water extraction are those set down in Ag. Mem 580; the procedures for allocating rainfall are those in section 5.3.

7.2 Since the procedures for allocating rainfall down the profile are perhaps based on the fewest physical data, there is a need for further detailed observations with this problem in mind. Ideally such observations would be based on a range of sites and not for example, exclusively on "minimum cultivation" sites.

8. Acknowledgements

This work would not have been possible without the active co-operation and interest of members of the Field Drainage Experimental Unit.

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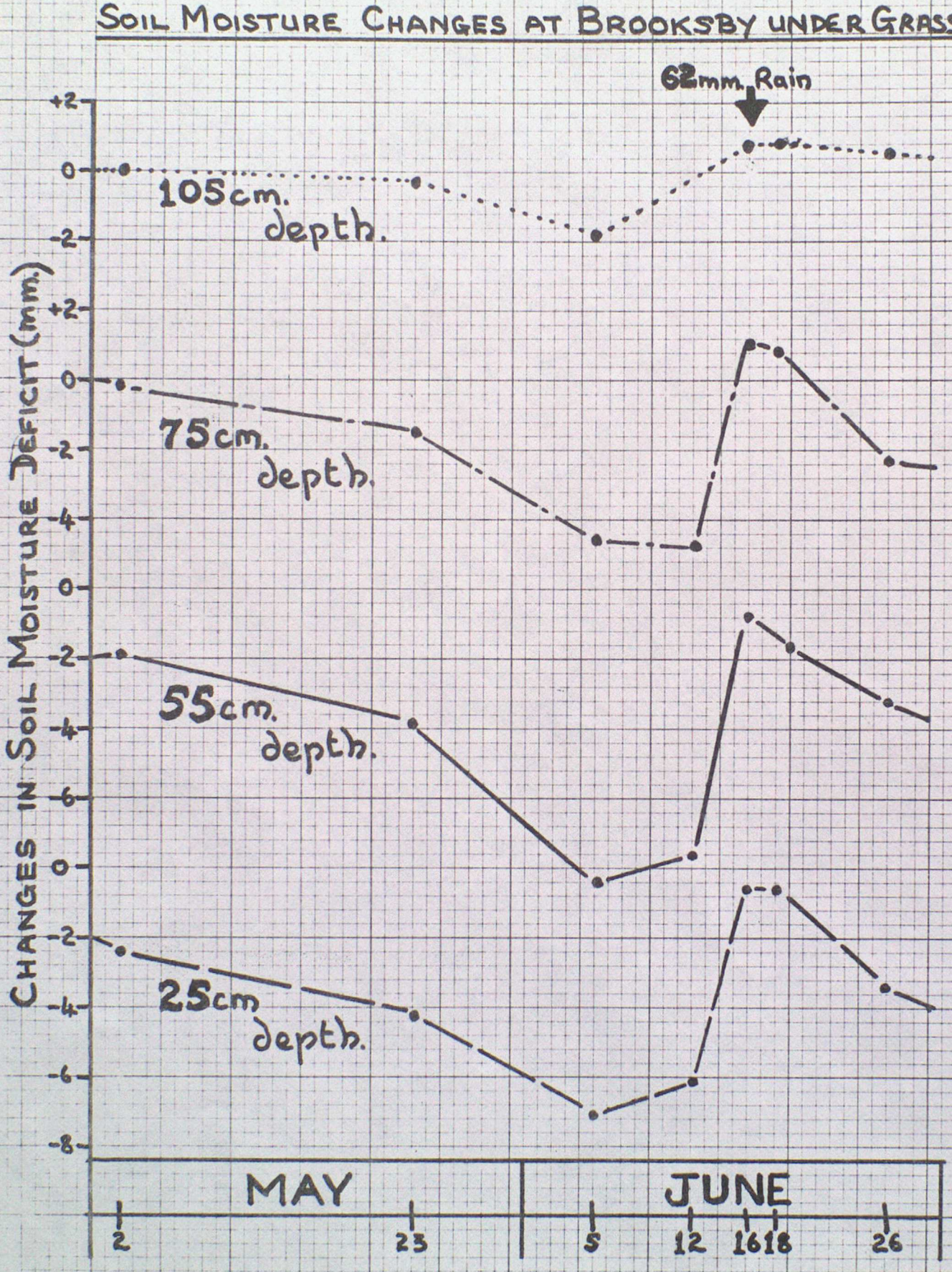
SOIL MOISTURE CHANGES AT BROOKSBY UNDER GRASS
62mm. Rain
105cm. depth.
75cm. depth.
55cm. depth.
25cm depth.
CHANGES IN SOIL MOISTURE DEFICIT (mm.)
+2
0
-2
+2
0
-2
-4
0
-2
-4
-6
0
-2
-4
-6
-8
MAY
JUNE
2
23
5
12
16
18
26